

**INTERNATIONAL ENERGY AGENCY
HYDROGEN IMPLEMENTING AGREEMENT
TASK 11: INTEGRATED SYSTEMS**

**Final report of Subtask A:
Case Studies of
Integrated Hydrogen Energy Systems**

Chapter 6 of 11

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Chapter 6

INTA SOLAR HYDROGEN FACILITY

1. PROJECT GOALS

Solar photovoltaic conversion for electricity production is well established in Spain at an industrial and commercial level. The combination of PV and electrolysis technologies to produce hydrogen, store it, and use it in fuel cells for times when the sun is not shining is a way to supply “solar energy” at night or on cloudy days.

With this idea in mind, and given the nature of INTA (Instituto Nacional de Técnica Aeroespacial; Huelva, Spain) as an aerospace-related institution, a program was started in 1990 with the following goals:

- Study the feasibility of solar hydrogen production
- Evaluate different component technologies
- Stimulate Spanish R&D in this field, looking towards component development
- Analyze the use of such concept for terrestrial applications.

Within this framework, INTA started a program, partially funded by the regional government of Andalucía. This program was divided into several subprograms, according to funds availability:

- Feasibility study of solar hydrogen as an alternative fuel
- Analysis of solar systems to produce hydrogen
- Definition, design, construction and start-up of a pilot plant for solar hydrogen production
- Characterization of components (PV field and electrolyzer)
- Annual operation of the system
- Definition, design, construction and start-up of a double storage system for the solar hydrogen production pilot plant
- Evaluation of the storage system
- Integration and evaluation of a phosphoric acid fuel cell (PAFC) into the Solar Hydrogen Production Facility.

2. GENERAL DESCRIPTION OF PROJECT

The INTA program on hydrogen technologies had two main objectives, as defined in 1989:

- The use of hydrogen as a storage medium for solar electricity
- The use of integrated systems: PV, electrolysis, hydrogen storage, and fuel cells for manned space missions.

The space related activities were abandoned on 1993. Since 1994, hydrogen activities were concentrated on the utilization of hydrogen in fuel cells in a non-centralized electricity generation services sector as well as a clean fuel for transportation.

The Solar Hydrogen Pilot Plant consisted of three phases. Figure 6.1 shows the general configuration of the facility. The pilot plant for solar hydrogen production (Phase I) was designed, constructed and evaluated during 1991-93. The storage system (Phase II) was defined and

The diagram illustrates a three-phase process for solar hydrogen production and utilization:

- PHASE I: Solar H_2 Production (1991 - 93)**
 - A **PV Field** (represented by a blue grid) is connected to an **Electrolyzer** (represented by a green cylinder).
 - The **Electrolyzer** produces **H_2** gas, which is then stored in an **H_2 TANK** (represented by a red circle).
- PHASE II: H_2 Storage (1993 - 95)**
 - The **H_2 TANK** is connected to a **Compressor** (represented by a red circle with a 'P' inside).
 - The compressed **H_2** is then stored in **H_2 Bottles** (represented by three red cylinders).
 - The **H_2** is then fed into a **Hydrides Container** (represented by a green rectangle), which is cooled by **Cool & Hot Water** (indicated by blue arrows).
- PHASE III: H_2 Utilization (1994 - 96)**
 - The **H_2** from the **Hydrides Container** is fed into a **PAFC Stack** (represented by a green rectangle).
 - The **PAFC Stack** produces **DC** (Direct Current) electricity, which is then converted to **AC** (Alternating Current) by an **Inverter** (represented by a green rectangle).
 - The **AC** is then used for **Resistive Load** (represented by a green rectangle) and **Grid** (represented by a green rectangle).
 - The **PAFC Stack** also produces **$CO_2 + H_2$** (indicated by a red arrow).
 - The **$CO_2 + H_2$** is then fed into a **Chromatograph** (represented by a green rectangle) and a **Reformer** (represented by a green rectangle).
 - The **Reformer** also takes in **Methanol** (indicated by a blue arrow) and **Air** (indicated by a green arrow).
 - The **Reformer** produces **$CO_2 + H_2$** (indicated by a red arrow) and **Exhaust** (indicated by a red arrow).
 - The **$CO_2 + H_2$** from the **Reformer** is then fed back into the **PAFC Stack**.

- 8.5 kW_p photovoltaic field
- 5.2 kW alkaline electrolyzer
- 24 m³ metal hydride (TiMn₂) storage
- Conventional pressurized gas installation for bottles of 8.8 m³ at 200 bar
- PAFC of 10 kW
- Two PEMFC stacks of 2.5 and 5 kW (hydrogen/air).

Table 6.1 and Table 6.2 present the main characteristics of the Phase I facility. These characteristics, together with properties of the other components of the system will be presented in the subsequent sections.

Table 6.1: Facility Arrangement for Phase I

Power Generation System:
8.5 kW solar photovoltaic field
7.4 kVA AC-DC converter
AC-DC MPPT power conditioning
Electrolysis System:
5.2 kW alkaline electrolyzer
Control System:
Process supervision
H ₂ supervision
Data Acquisition System (DAS)
External bus data logger
Distributed data acquisition cards
Host computer
Auxiliary systems:
Water treatment
GN ₂ supply
Fire protection
Uninterrupted power supply
Cooling water supply

Table 6.2: System Characteristics for Phase I

Photovoltaic Field:
8.5 kW _p at 1 kW/m ²
and 25°C cell temperature
144 BP Solar modules (260S)
Electrolyzer
Alkaline Electrolyzer (METKON)
5.2 kW at nominal 108 A, 48 V
H ₂ production: 1.2 Nm ³ /h
H ₂ purity : 99.7% ± 0.1% vv
Operational conditions:
6 bars, 80 °C, 30% KOH
Water treatment:
Activated carbon filter
Ionic exchange resins filter bed
GN ₂ supply:
Steel bottles type B50
10 Nm ³ N ₂ , 200 bar
N ₂ purity:100 ppm H ₂ O, 50 ppm O ₂

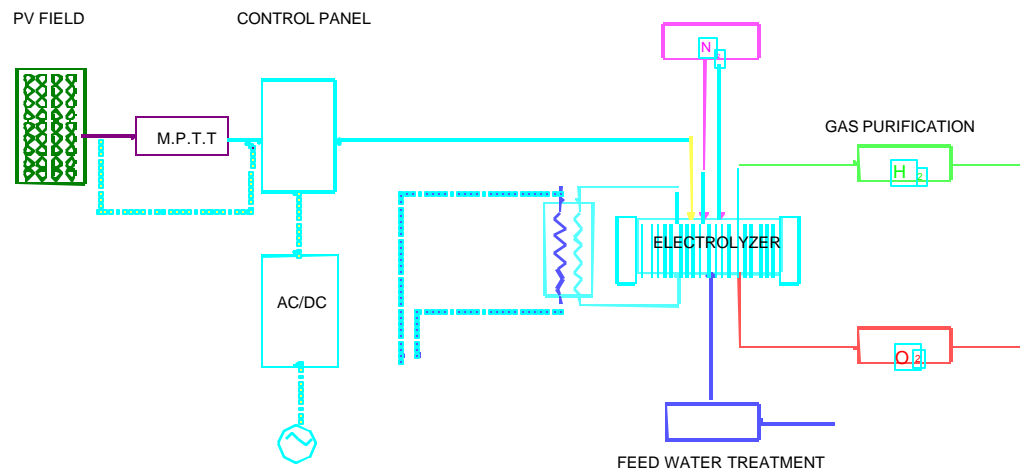


Figure 6.2: Schematic view of PV and electrolyzer

The electrolyzer can be powered in three different ways:

- Direct connection mode from the PV array (with constant or variable number of active electrolyzer cells), or
- Through the Maximum Power Point Tracker, or
- By means of an AC-DC converter.

This last option has been used to characterize the electrolyzer under steady state conditions.

3.1.1 Photovoltaic Field

The PV field, shown in Picture 6.1, is composed of 144 modules (36 cells each), 30% of which have 8 connectors to place output voltages and currents at intervals of 9 cells (4.5 V and 3.35 A). This flexible module configuration enables the installation of different matching systems and adjustment of the PV field and electrolyzer's operation.

The first experiment was performed under the direct coupling mode with a PV configuration of 36 parallel strings and 117 cells connected in series (3 1/4 module).

3.1.2 Electrolyzer

The electrolyzer, shown in Picture 6.2, is equipped with an adjustable control unit that allows both automatic and safe operation, and different operation modes. To provide optimum direct coupling with the PV field, the control unit can select the number of operating cells as a function of the solar radiation:

- 24 cells: 120-90 A (1000-720 W/m²)
- 25 cells: 90-60 A (720-500 W/m²)
- 26 cells: 60-30 A (500-200 W/m²)

3.2 Phase II - Storage System

The hydrogen produced by the electrolyzer is initially stored in an intermediate buffer, from which it can be transferred to one of the two storage systems: metal hydride storage or pressurized gas (at 200 bar). Tables 6.3 and 6.4 summarize the characteristics of the metal hydride and pressurized gas systems, respectively. The storage system is shown in Picture 6.3.

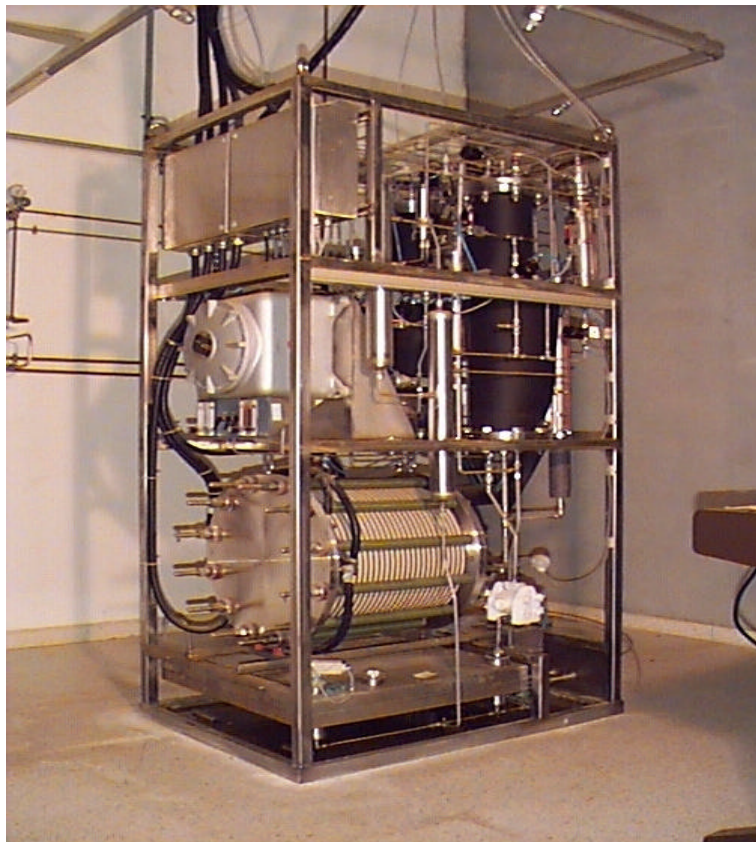
3.2.1 Metal hydride storage

The metal hydride storage system consists of an intermediate buffer, a hydrogen purification unit, a metal hydride container and a cooling water supply system. Suitable instrumentation and sensors were prepared in order to control the system and acquire data for later evaluation.

The intermediate buffer is connected to the electrolyzer hydrogen delivery valve. Once set point pressure is reached, hydrogen passes through the purification unit and fills up the hydride container.



Picture 6.1: Photovoltaic field



Picture 6.2: Electrolyzer

Table 6.3: Hydride Storage

Intermediate buffer:

Geometric capacity: 1000 l
working pressure: 6 bar

Purification unit

Hydride container:

Manufacturer: GfE mbH
HIDRALLOY C20, based on TiMn_2
Nominal capacity: 24 m³ hydrogen
designed pressure: max. 10 bar (80°C)
discharge pressure: min. 2 bar (70°C)
charge pressure: min. 2 bar (15°C)
weight: approx. 210 kg
dimensions: approx. 1600 x 300 mm

Table 6.4: Pressurized Gas Storage

Intermediate buffer:

geometric capacity: 1000 l
working pressure: 6 bar

Purification unit

Air driven gas booster compressor:

Haskel Energy Systems
model: AGD4-AGT 15/30
two units, three stage
inlet H₂ pressure: min. 2.6 bar
outlet H₂ pressure: max. 240 bar
air driven pressure: min. 6.2 bar

Compressed air supply:

air compressor, 10 H.P.
two cylinders, two stages

GN₂ supply:

Steel bottles B50, 10 Nm³, 200 bar



Picture 6.3: Storage System: intermediate buffer (left), horizontal hydride container tank (middle), and 200-bar bottle and compressor (right).

The hydride storage container consists of a pressurized tank filled with metal hydride powder, a cooling/heating shell, water supply and hydrogen supply provided with safety and shut-off valves. This hydride container was manufactured by GfE mbH, from Nürnberg, Germany.

A solar thermal collector facility supplies hot water at 80°C. Cooling water at 15°C is available on site.

3.2.2 Pressurized gas storage

The pressurized gas storage system uses the same intermediate buffer and the purification unit as the metal hydride storage system.

When hydrogen is stored as a compressed gas, hydrogen passes from the intermediate buffer to a two-stage air driven gas booster compressor that increases the hydrogen pressure to 200 bar. Hydrogen is bottled in metallic cylinders with 8.8 Nm³ of hydrogen capacity at 200 bars. The hydrogen purity is measured by a Teledyne analyzer. Additional sensors and manometers give information about the process. Nitrogen gas is available on site to proceed with shut-down and start-up under safe conditions.

3.3 Phase III - Fuel Cells

A 10 kW PAFC supplied by ERC was installed at the end of 1993. The PAFC system also consists of a methanol reformer to permit operation with methanol. The general layout of this subsystem is displayed in Figure 6.3, and the plant is shown in Picture 6.4.

3.3.1 10 kW Phosphoric Acid Fuel Cell

The stack has 135 bipolar single cells connected in series that supply a maximum current of 125 A and 85 volts. The open circuit voltage is 130 V.

The electrolyte is 98% PO₄H₃ and the electrodes are fed countercurrently with H₂ and air. The unit is cooled by air in cross flow every fifth cell. Atmospheric air is used for equipment and cathode feed.

3.3.2 Methanol Reformer

To test the operation of the power plant with fuels other than pure hydrogen, a methanol reformer has been coupled to the fuel cell. The reformer consists of a catalyst bed of Cu-Zn, a vaporizer-heater, and a liquid fuel burner (methanol) during start up and hydrogen burner when coupled with fuel cell tail gas. The operating temperature is about 370°C and the methanol/hydrogen conversion rate amounts to >90%.

3.4 Auxiliaries

Several auxiliaries have been used to assure proper operational behavior of the system:

- Feed water treatment unit
- Gases supply section
- Fire protection system
- Uninterrupted power supply
- Cooling/heating water supply unit

The feed water treatment unit consists of activated carbon filtering as pretreatment and ionic exchange resins filter bed as final treatment of the electrolyzer feed water.

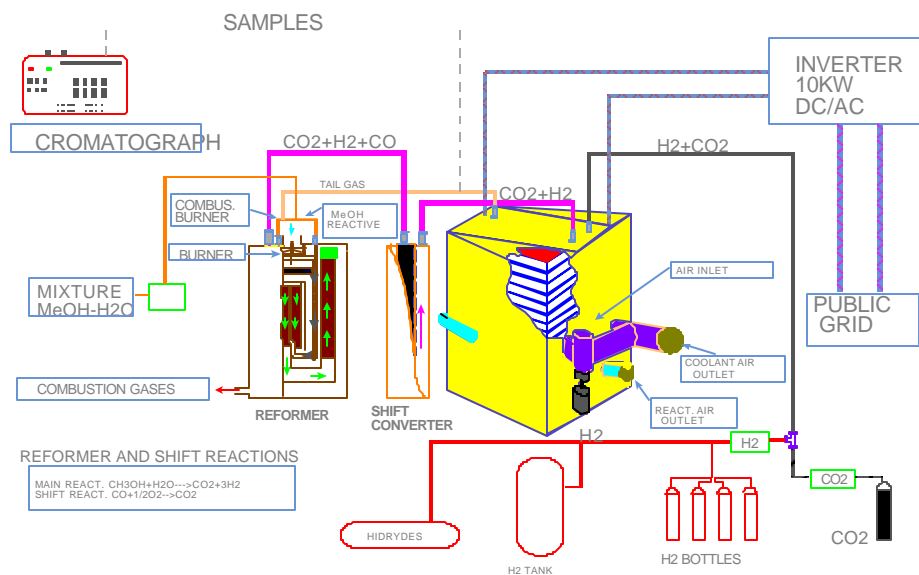
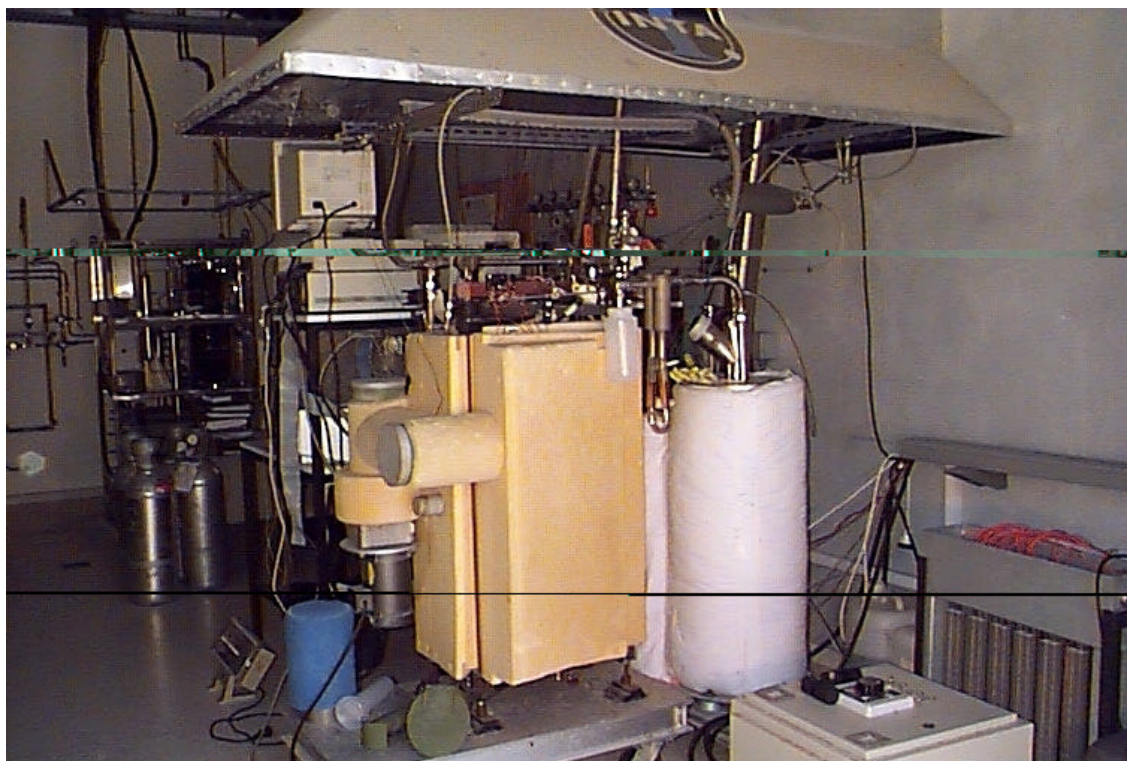


Figure 6.3: Schematic view of the 10kW PAFC Power Plant



Picture 6.4: Phosphoric Acid Fuel Cell

The gas supply section provides gases for electrolyzer pneumatic control and inertization during start up and shut down (nitrogen), and compressed air for the PAFC and for the air driven compressor operations.

The fire protection system for the facility includes adequate sensors and a control panel for taking appropriate actions, if required.

Uninterrupted power supply enables proper operation of the control systems and sensors in case of loss of electricity from the public grid.

Cooling/heating water supply facilities provide cooling for the electrolyzer and hydride container during the charging process and heating of the hydride container during the discharging process.

4. INTEGRATION OF COMPONENTS

The PV configuration (number of panels in series and in parallel chains) was calculated as a function of the electrolyzer characteristic curve. The optimum configuration is a perfect match between the maximum power line of the PV field and operating characteristic line of the electrolyzer. Unfortunately, it is not possible to get such a “perfect” match between both systems, so that it is necessary to use a DC-DC converter (Maximum Power Point Tracer) to follow the maximum power line of the PV field. In this project, a new approach to solve this problem was used: modifying the number of operating cells of the electrolyzer. In this way, the characteristic curve of the electrolyzer was “adapted” to the Maximum Power Line of the PV Field.

Figure 6.4 shows how the electrolyzer characteristic lines change by operating with 24 cells between 1000 and 700 W/m², 25 cells between 750 and 500 W/m² and, finally, with 26 cells for a global radiation lower than 500 W/m². The hydrogen production section is decoupled from the utilization by the storage system.

The control system of the facility was designed in a decentralized way, so that each subsystem has its own independent control system.

In the electrolyzer control cabinet the correct operation of the electrolyzer is supervised by adjusting the number of operating cells for optimum match with the PV Field (in case of variable cell number operation). The system also takes any necessary action to adjust the electrolyte temperature, and hydrogen delivery pressure to the specified set point. It also checks the hydrogen purity to send the hydrogen to storage or to vent, in case of unacceptable purity. If a dangerous composition is detected, the control system shuts down the electrolyzer.

The storage control system provides several actions in order to guarantee proper operation. The controller takes action in case of high or low pressure in the intermediate buffer, in case of abnormal pressure and temperature inside the hydride tank, when the chemical composition of the hydrogen stream is out of limits. Finally, it checks cooling water availability to prevent overpressurization of the hydride container.

The PAFC control system adapts the hydrogen flow to the stack according to the load level requested. It also controls the temperatures and voltages of the reformer and stack to ensure proper operation of the system.

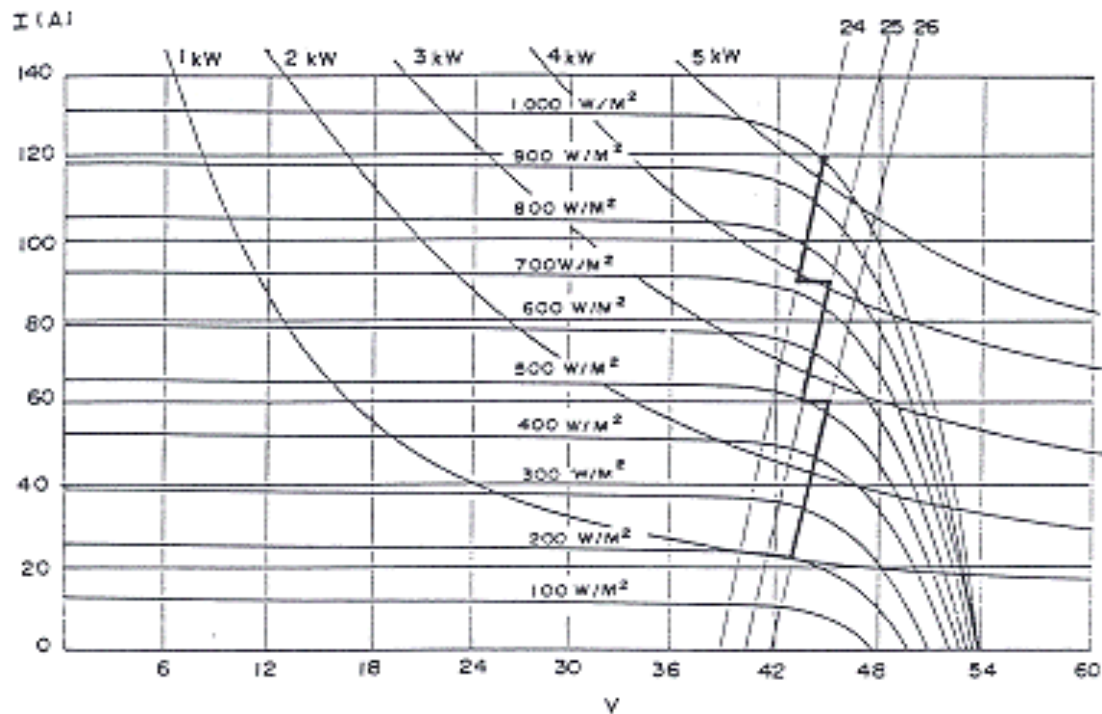


Figure 6.4: Regulation strategy of electrolyzer cell number as a function of solar radiation

5. OPERATIONAL EXPERIENCE AND PERFORMANCE

The use of a storage system between production and utilization section has the advantage of decoupling production and utilization operations. Based on this decoupling, components of the facility were evaluated in several steps.

5.1 Phase I - Solar hydrogen production section

Hydrogen production operated automatically for one year, in one of two operation modes:

- Direct connection between the PV field and electrolyzer with a constant number of operating cells (24)
- Direct connection with varying number of electrolyzer operating cells (from 24 to 26)

The main objectives of the test plan were to:

- Determine voltage, Faraday, and energy efficiencies of the electrolyzer during the testing period
- Calculate energy efficiency of the photovoltaic field coupled to the electrolyzer
- Study the global energy efficiency of the system and the dependence of operating/climatic conditions on such values
- Analyze the control system behavior, especially on cloudy days
- Perform a reliability study of the components
- Propose actions to improve the system's global efficiency

To meet these objectives, the system was instrumented and evaluated using methods proposed in literature.

Tests started in November 1992 and ended in October 1993. During this period, 122 tests were performed, for a total of 723 operating hours and accumulated hydrogen production of 408 Nm³. Of these 723 hours, the system operated 392 hours under constant cell mode, and 331 under the varying cell mode.

The system was operated for 104 days from sunrise to solar noon and 18 from sunrise to sunset.

The electrolyzer was characterized under predefined steady state conditions for 150 operation hours. Thus deterioration is easily detected.

5.1.1 Experimental Results

This section presents experimental results of daily and yearly behavior analysis and the influence of the number of cells on the system's behavior.

Daily behavior of the system

Figure 6.5 presents the analysis of Faraday, voltage, and energy efficiency evolution for a sunrise-to-sunset operating day. It shows that the Faraday efficiency is very close to 100%, excluding the sunrise and sunset period when global solar radiation is lower than 400 W/m². The density current feeding the electrolyzer is low, thus the voltage efficiency is high. Regarding the electrolyzer energy efficiency, values between 70% and 80% were reached during almost all of the operating period, with the exception of sunrise and sunset.

Figure 6.6 presents photovoltaic field and global system efficiencies for a day of operation. During sunrise, the PV efficiency increases continuously as the match between PV field and electrolyzer improves. At solar noon, the efficiency decreases due to high PV cell temperatures. PV field efficiency ranges from 8% to 9%. Global system efficiency, a product of the former efficiencies, is between 5.8% and 6.5% for almost all the operating period.

Daily efficiencies were:

- PV field efficiency: 8.34%
- Energetic electrolyzer efficiency (LHV): 69.65%
- Global system efficiency: 5.71%

During the test period it was noted that daily efficiencies strongly depend on the duration of operation. Figure 6.7 and Figure 6.8 present daily Faraday, voltage, energetic and global system efficiencies as a function of the operation period. Assuming that operation starts under the same conditions, the average Faraday efficiency increases with operating hours for the period. An asymptotic tendency can be observed.

Yearly evaluation of the system

Yearly evaluation of the system was done using daily average results of the different variables.

Figure 6.9 presents the evolution of the daily global efficiency of the system as a function of operating hours. Each value represents one daily global efficiency of the system during the testing period, and range from 5.2% to 6.3%. The dispersion observed is due to diverse operational conditions: test duration, climate conditions, and operation mode.

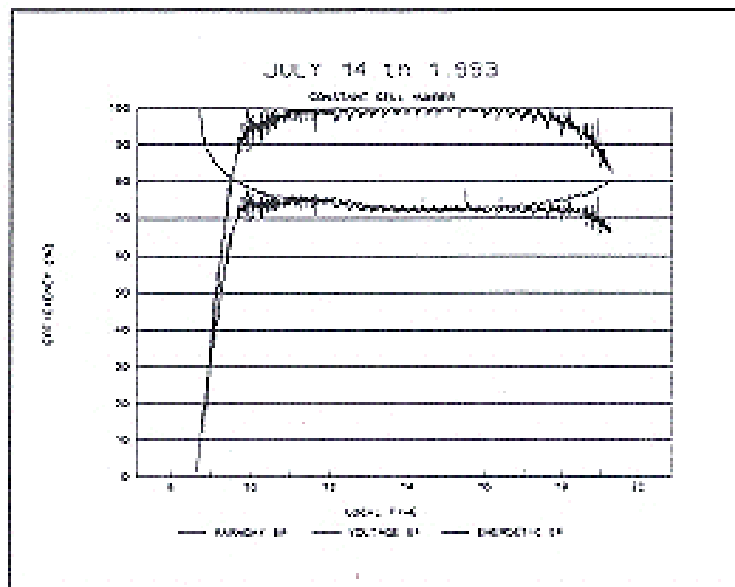


Figure 6.5: Evolution of Faraday, voltage and energetic electrolyzer efficiencies during one day

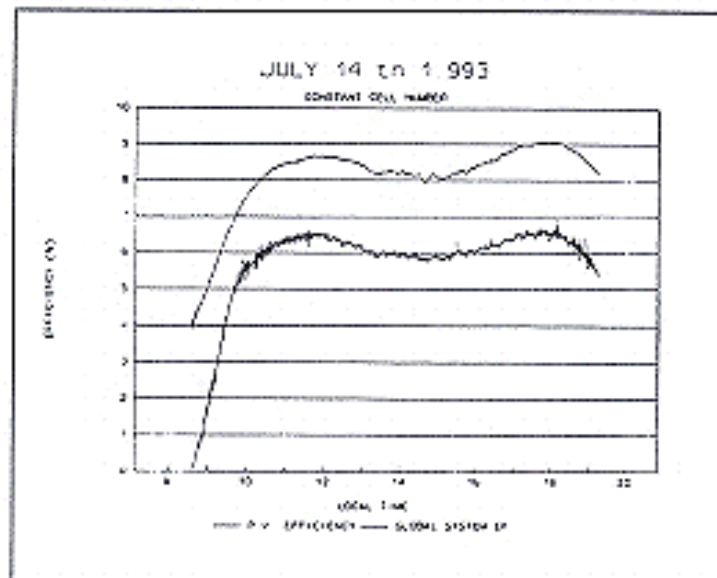


Figure 6.6: Evolution of PV and global energetic system efficiencies during a day of operation

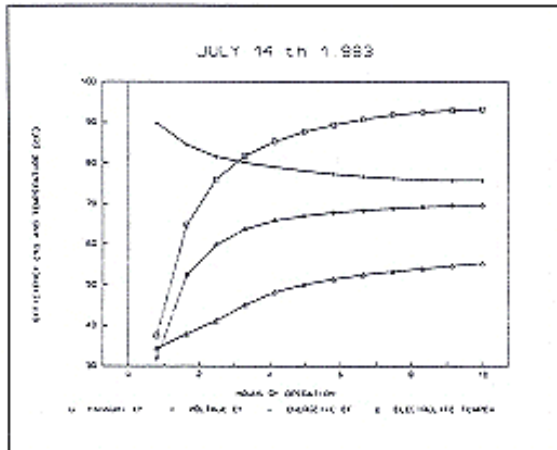


Figure 6.7: Influence of test duration on daily efficiencies and electrolyte temperature

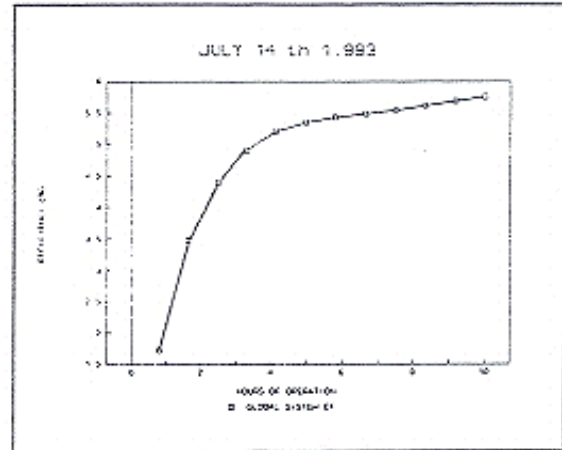


Figure 6.8: Influence of test duration on daily global system efficiency

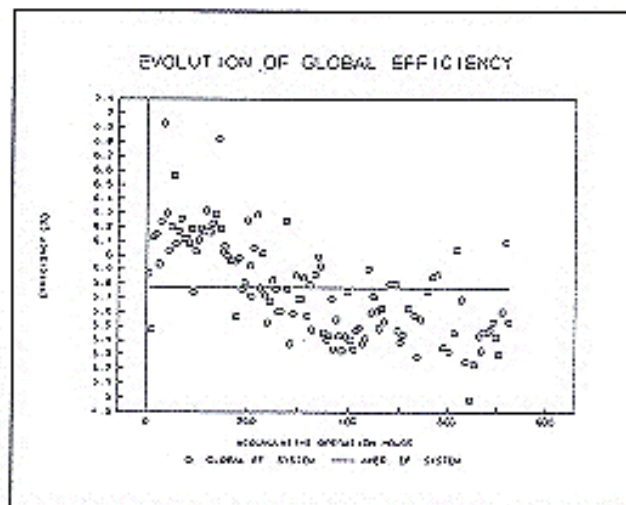


Figure 6.9: Evolution of global system efficiency during the testing period

Figure 6.10 presents the global energy balance of the system applied to 122 operational days. All the efficiencies in this figure refer to incident energy on photovoltaic field (100%).

Yearly average efficiencies were:

- PV efficiency: 8.35%
- Electrolyzer energetic efficiency (LHV): 69.13%
- Global system efficiency: 5.70%

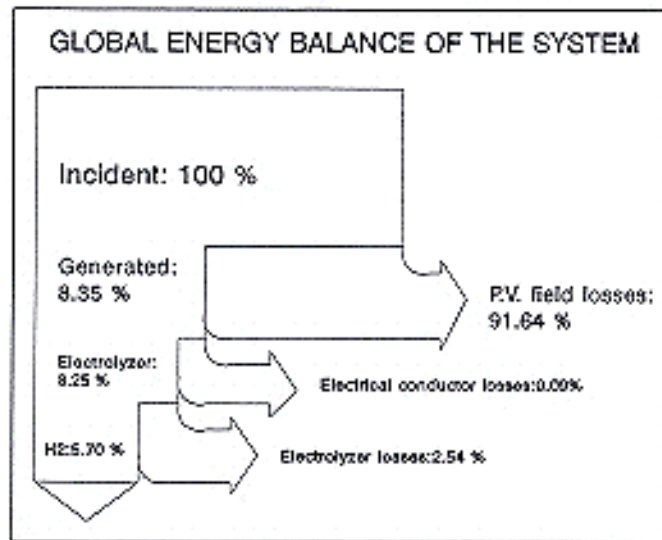


Figure 6.10: Global energy balance of the system for one year period

Influence of operation procedure

Figure 6.11 shows the characteristic intensity-voltage curves of the PV field for global solar radiation between 270 and 978 W/m². The intensity-voltage curves of the electrolyzer working with constant and varied number of operative cells have been superimposed.

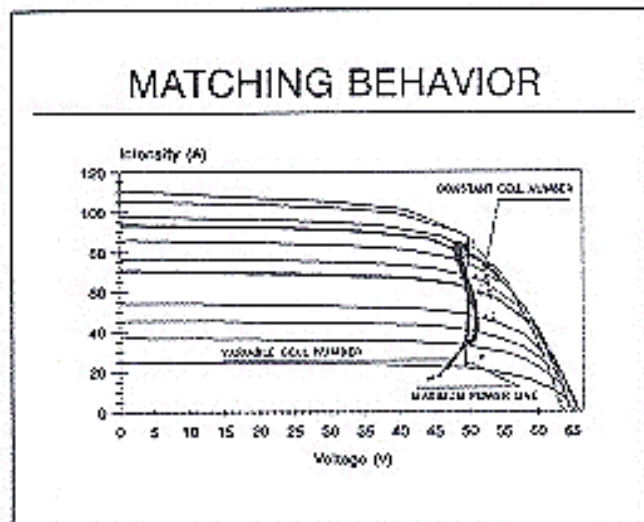


Figure 6.11: Matching behavior of operation modes

It can be concluded from Figure 6.11 that:

- The match between electrolyzer and PV field is slightly improved with a varied number of cells.
- The match is working well with a constant number of cells.

Electrolyzer deterioration

The electrolyzer was characterized every 150 operational hours under standard conditions using the AC-DC converter, to determine any possible deterioration as a function of working hours.

Figure 6.12 shows the electrolyzer energy efficiency as a function of intensity for five successive time periods. As yet, no deterioration has been detected in electrolyzer performance.

5.2 Phase II - Storage Section

In order to characterize the system, the following main components were identified:

- Metal hydride container
- Gas booster compressor

The metal hydride container was characterized during the charging process from a kinetic and capacity point of view.

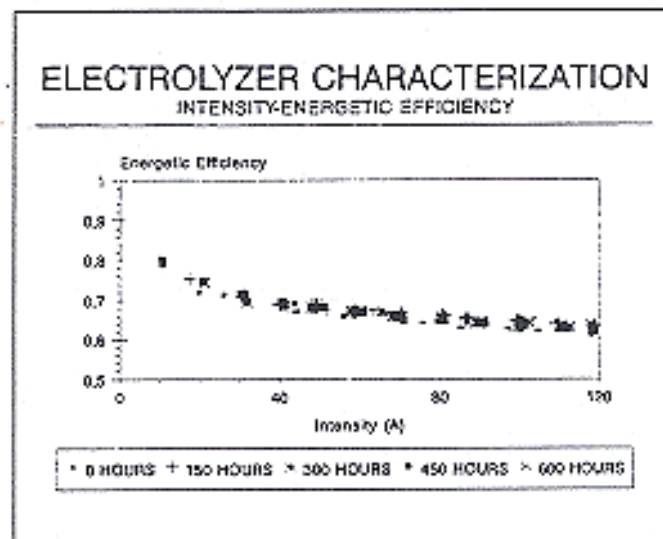


Figure 6.12: Evolution of electrolyzer efficiency during the testing period

In both cases, the initial conditions in the hydride container were:

- Temperature fixed at 8°C
- Hydrogen pressure at 0.5 bar

The hydrogen used had a purity level of >99.999%, with a level of impurities of 3 ppm H₂O and 2 ppm O₂. The charging pressure was limited to <10 bar during the process due to safety considerations.

Figure 6.13 shows the results of the kinetics test. The test focused on obtaining the maximum value of the charging rate. This value was achieved at the initial moments of the process.

The maximum value obtained was approximately 360 Nliters/min. A value around 170 Nliters/min was achieved after 5 minutes, and decreased slowly with time.

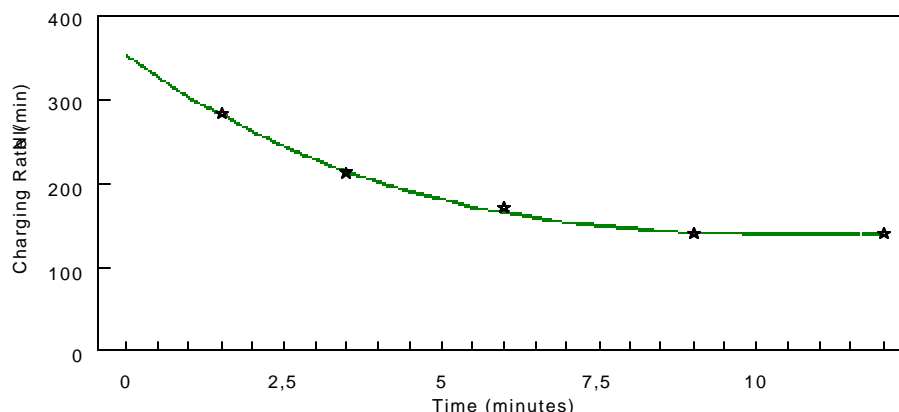


Figure 6.13: Kinetics test of metal hydrides

Figure 6.14 shows the results of the capacity test. From the initial conditions mentioned above, the hydrogen volume absorbed in the charging process was 22 Nm³, close to the 24 Nm³ nominal capacity.

The characterization of the other two main components of the system consisted of testing the rate of compression of the hydrogen booster compressor. Figure 6.15 shows the evolution of the volume of hydrogen compressed up to 200 atm in a bottle vs. time. The time employed filling the bottle was 2.7 hours.

5.3 Phase III - PAFC Performance

The electrical efficiency of the PAFC was obtained as a ratio between power delivery and the energy content of the hydrogen flow consumed (based on LHV). The I-V electrical efficiency is shown in Figure 6.16 for a wide intensity range.

Electrical efficiency at nominal conditions is around 50%. For a selected intensity, i.e. 80 A, efficiencies range between 50% and 40%, due to the influence of electrolyte temperature on final efficiency of the system. Since start up of the system, the loss of efficiency is estimated to be 20%. A test program is scheduled to be carried out to determine efficiency evolution as a function of working hours.

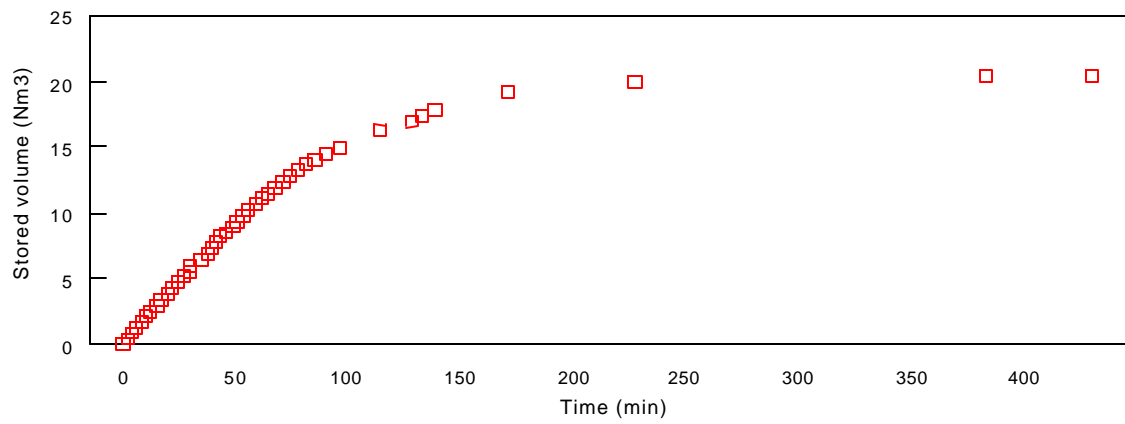


Figure 6.14: Capacity absorption of metal hydride tank

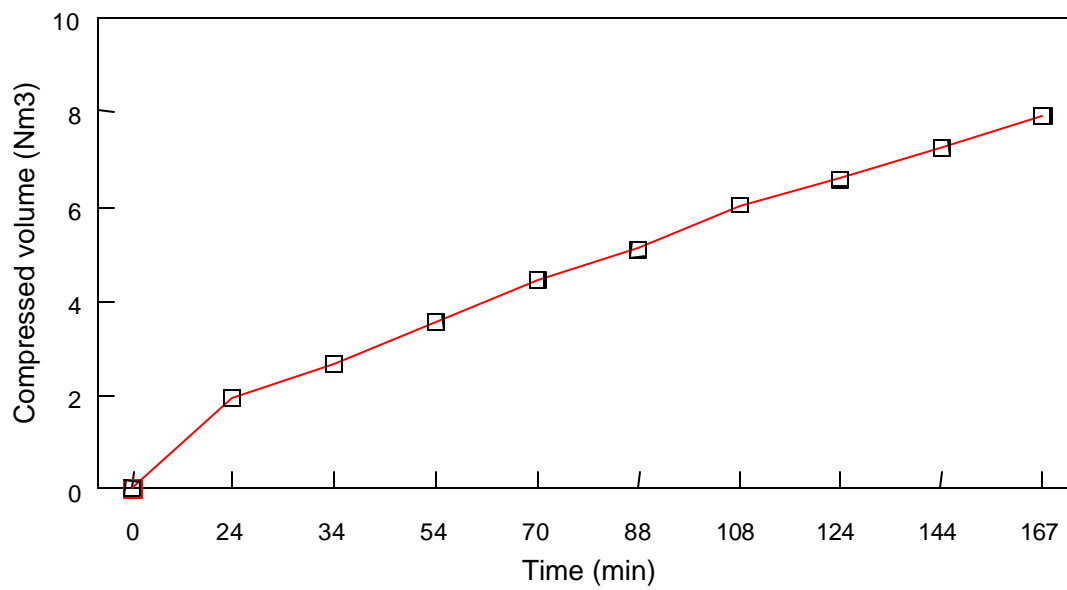


Figure 6.15: Compressor characterization

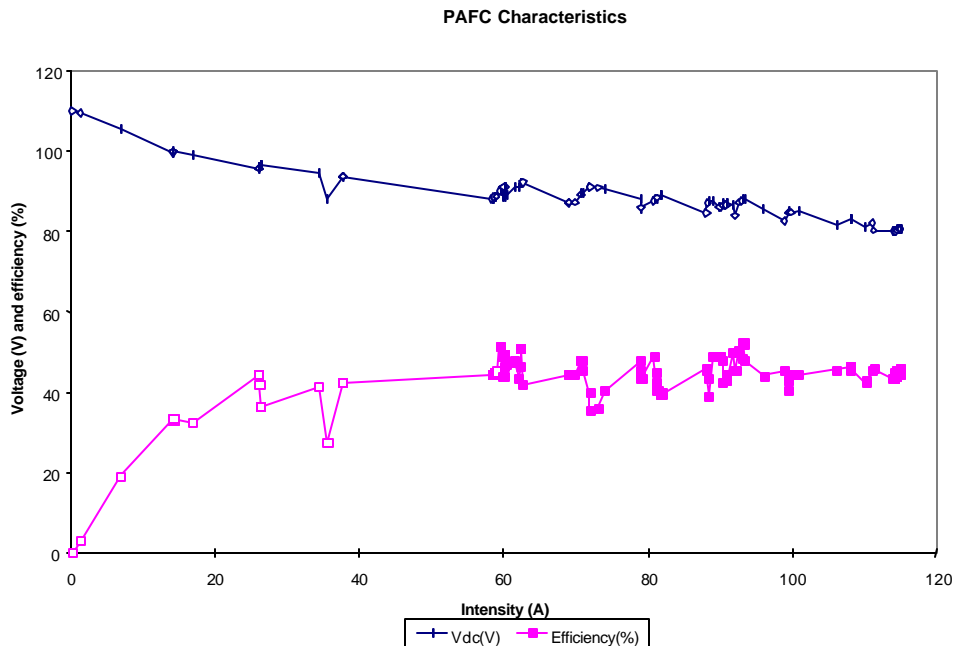


Figure 6.16: Performance of the PAFC

5.4 Integrated operational experiences

In concert with the commercial nature of all components used in the plant, acceptance tests carried out before installation of components showed good agreement with technical specifications given by the manufacturers, so that it was not necessary to modify the preliminary designs for the correct operation of the system.

Integration between the PV field and electrolyzer showed satisfactory results in direct connection mode and very good results operating in direct connection with variable cell numbers.

The PAFC is decoupled from the production section by using the storage section, so there is no real integration between the two subsystems.

The system was in continuous operation for three years until the evaluation program was finished. Since then, the system is periodically operated.

The most critical component of the system was the pneumatic feed water pump of the electrolyzer. No solution was found to the periodic malfunction of the pump. Each year, it is necessary to replace the membranes of the pump.

Due to the operational sequence during start up and shutdown, inertization of the system with nitrogen is required. Some small quantity of nitrogen goes to the storage section, resulting in a decrease of the kinetic absorption rate in the hydride container. Once the effect of such "nitrogen contamination" was evaluated, it was decided to modify the start up and shutdown electrolyzer sequences, minimizing inertization operation.

The time to reach steady state conditions is usually 2 hours from sunrise. During this period, the electrolyzer temperature and, consequently, the efficiency of the system, are below their nominal values. This problem can be solved by isolating the liquid-gas separator vessel of the electrolyzer and by using the AC-DC converter to reach nominal electrolyte temperature in less than 20 minutes.

Using the automatic control system of the production side, this part of the plant is suitable for unattended all-day operation. The utilization subsystem has a manual control system, thus precluding unattended operation.

Finally, it must be stated that it is quite difficult in many cases, to find components of optimum size for small-scale integrated facilities such as this one.

6. DATA ACQUISITION SYSTEM

This system registers the operational parameters of the PV field, electrolyzer, storage system, PAFC, and auxiliary subsystems. It also records data on a computer hard disk for later evaluation and enables a graphics monitor presentation of the plant status and trend diagrams.

Configuration of the data acquisition system is based on an external bus, connecting a number of distributed acquisition cards with the host computer. Commercial software (Iconics GENESIS) was used for the acquisition and surveillance functions. The PAFC data acquisition system is composed of a DataLogger FLUKE HYDRA and National Instrument internal PC Card. The software used is LabWindows from National Instrument.

The following signals are read and stored by the system:

- Photovoltaic field:
 - Intensity and voltage
 - Cell and ambient temperature
 - Global solar radiation on the panel's plane.
- Electrolyzer:
 - Voltage and intensity
 - Electrolyte inlet and outlet temperature
 - Hydrogen flow
 - System pressure
 - Hydrogen and oxygen analysis
 - Hydrogen and oxygen separator's level.
- Hydrogen storage system:
 - Hydrogen purity
 - Water temperature at inlet/outlet of hydride container
 - Hydride container inlet/outlet hydrogen pressure
 - Hydride container water flow
 - Hydride container hydrogen flow
- PAFC System:
 - Voltage and current of the system

- Voltage each 10 cells (fourteen measurements)
- Mass flow of hydrogen and of carbon dioxide
- Stack temperature at 15 locations
- Reformer temperature at 13 locations
- Mass flow of methanol to reformer
- Chromatographic analysis:
 - * Composition of gas at exit of reformer burner
 - * Reformed gas before and after shift conversion
 - * Gas composition at anode and cathode exit
- Utilities:
 - Cooling water flow
 - Inlet and outlet cooling water temperature
 - Feedwater temperature and conductivity
 - Pressure losses

Any abnormal events that trip an alarm are also recorded.

7. PUBLIC ACCEPTANCE AND SAFETY ISSUES

There is no special public sensitivity concerning production and use of hydrogen in Spain. It is considered an industrial gas whose main risks are derived from its flammable nature and its storage at high pressure. From a legal point of view (regulation that must be taken into account to design industrial installations) hydrogen is treated in the same way as natural gas. There are special regulations concerning materials that come in contact with hydrogen.

Taking into account the lack of legislation concerning use of hydrogen in several fields (i.e automotive), a project funded by the EU under the THERMIE program is underway with participation by INTA. The main goals of the European Integrated Hydrogen Project are:

- Identification of deficits impeding harmonization of rules, regulations, licenses and approval procedures.
- Harmonized approaches to develop standardized rules, regulations, licenses and approval procedures
- Preparation of a more profound basis for discussion
- EU wide accepted improved safety equipment
- Preparation of concepts for standardized infrastructure components.

8. FUTURE PLANS

INTA's next step toward introduction of these technologies is directed to the use of major components in the automotive sector. The focus is centered on the storage system and the PEM fuel cell. A collaborative project with an automotive company, with participation of a university, is under way in a regional project aimed at bringing promising high technology to an energy-intensive consumer application, i.e., vehicles.

9. CONCLUSIONS

INTA's solar hydrogen production, storage and utilization facility has been in operation successfully for a long period of time. The main objectives have been reached and great interest from the scientific community concerning the potential of these technologies for human use continues.